

**Carbon in the Former Soviet Union: The Current Balance**  
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*"The general purpose of this research is an appraisal based on satellite imagery of the area (and standing stock of carbon) of forests of the former Soviet Union. The purpose extends to measurements of changes in the standing stock and the development of a potential for monitoring those forests. There is still considerable uncertainty and discrepancy among estimates of forest area in Russia, whether the area is expanding or contracting, and whether carbon is being accumulated in, or lost from, Russian forests. The research carried out with this grant is collecting satellite and ground data and developing methods to be used for a clarification of these uncertainties and discrepancies." (NAGW-3856, Annual Report 1995)*

The three questions are being addressed as follows:

1. **What is the area of forest in the former Soviet Union?**  
 We have used a 10-year data set of the GVI (15-km) to obtain a land-cover map with 60 classes. We are generating a 1-km map with AVHRR LAC data.
2. **Has that area of forest changed over the last two decades?**  
 The Russian Forest Atlas (1973) and the Forest Cover Maps of Russia (1990), when digitized, allow an appraisal of the differences. Successional relationships aid in interpreting the periods of change.
3. **What is the total carbon content of these forests and its distribution spatially?**  
 We shall use the satellite-derived maps of land cover supplemented by mean monthly precipitation and temperature data to map carbon distribution. We shall have available data on the carbon content of forests at the level of administrative districts and biomass estimates of 2,000 sites from N.I. Bazilevich.

**A Review of Progress in Year 2**

We developed a 60-class, 15-km resolution landcover map of the former Soviet Union based on the phenology from NOAA GVI data from over a period of 10 years. These classes have been labeled according to the terminology of J. Olson.

We have acquired data from N.I. Bazilevich via D. Varlyguin on the productivity and biomass of some 2,000 sites in the former Soviet Union.

We have obtained and worked with 1-km AVHRR data in selected regions in Krasnoyarsk and Primorski Territories.

**Research Originally Proposed for Year 3**

Prepare a land-cover map for the former Soviet Union based on 1-km NOAA AVHRR LAC data from the IGBP Global Landcover Project through the EROS Data Center.

Compare our 60-class 15 km resolution land cover map with maps obtained from the Russian forest service (GUGK, 1990).

Compare the 1973 digitized map of Krasnoyarsk territory (1:2,000,000), the 1990 digitized map of Krasnoyarsk Territory (1:2,500,000), and our own satellite based map of Krasnoyarsk territory (1 km resolution).

Use the satellite-derived digital map created in this research with tabular data on carbon storage of Russian forests from V. Alexeyev and biomass data of the former Soviet Union from Bazilevich to develop a geographically based carbon map of Russia.

Use Landsat TM data to determine map quality in specific regions.

### **Year 3 Accomplishments:**

#### **A. Progress in creating a 1 km resolution Forest Map of the FSU**

Our methods have been modified as a result of the availability of 1 km data from the USGS/EROS Data Center. We had intended to retrieve data sets via the Internet, but retrieval was not feasible despite months of effort. We were also unsuccessful in acquiring the data directly from the DAAC via mail. Working with the EROS DAAC has been difficult. We have been requesting products from them that they are either unwilling or incapable of providing over the Internet. These difficulties were documented and forwarded to the LPDAAC Science Advisory Panel in a letter sent earlier this year. We made several suggestions for improvement in the operations of the DAAC regarding 1 km AVHRR data distribution.

Given the lack of success in obtaining these data, we evaluated the global 1km NDVI composite images. We downloaded six months of data (April to September 1992) via the Internet. From close inspection of these time series and via principal component analyses we determined that the methods used to collect these data will compromise their utility for land surface classification. Specifically, inter-image and intra-orbital seams are visible throughout, making it quite difficult to tell whether a numerical boundary is a processing flaw or a land cover boundary.

As a third approach, we are compiling a map using the best AVHRR LAC image resources available. For this effort, we have identified, acquired, and concatenated about 50 satellite images (~5 GB) from 1990 to 1993 to develop a 1 km surface for subsequent classification. We still require an additional 50 to 75 images; these scenes have been identified and ordered from EROS Data Center. NOAA AVHRR imagery that has already been acquired includes 28 dates from 1990, 29 dates from 1991, 8 dates from 1992 and 4 dates from 1993. All data have been projected to either a Lambert azimuthal equal area or an equirectangular map projection and have been radiometrically corrected. Currently, we estimate that we have summer (mid-growing season), cloud free coverage for 80 to 90% of the region of the FSU. Additional data will be obtained in November 1996.

#### **B. A 60 class, 15 km resolution land cover map of the FSU**

A 60 class 15-km resolution phenology land cover map of the region of the FSU was presented at the annual ESA meeting in Providence RI. (Stone, T. A., R. A. Houghton and P. Schlesinger, 1996. [abs.]. ESA Annual Meeting 1996, Providence. Supplement to the Bulletin of the ESA 77(3): 426). A paper is being prepared for publication.

#### **C. Digitizing the 1973, 1:2M scale Forest Cover Map of Krasnoyarsk Kray**

We are now digitizing the 1973, 1:2M scale Forest Cover Map of Krasnoyarsk Kray from the Forest Atlas for a comparison with the same region of the 1990 Forest Map (1:2.5M) of the USSR. Digitization of the 1973 forest map at a scale of 1:2M is incomplete; we expect to complete the map within the next few months. However, a comparison in the southern part of the of the Kray (approx. 215,000 km<sup>2</sup> or 10% of the total area of the Kray) showed large increases in the categories of Non-Forest, Birch, Fir, Scots Pine and Aspen and large decreases in Undefined Forest (literally, forests without species indicated), Burned Forest, Cut Forest, Outcrops/Stones and Sparse Arctic Birch. Although these changes were particularly evident near agricultural areas, it is unclear at present whether these differences are real or are simply re-classifications. It is clear, however, that large amounts of Undefined Forest in the older map were called Non-Forest in the more recent maps, and that increases in Birch, Scots Pine, and Aspen were in areas formerly called Non-Forest (Table 1).

This effort is made more difficult by map distortions and projections, lack of good control points, lack of map pedigree, and differences in map scale.

**Table 1.**

| 1990 Cover Type       | '73 to '90 Change | 1973 Source ( in order of importance) |                    |       |
|-----------------------|-------------------|---------------------------------------|--------------------|-------|
| Non-Forest            | + 6.7 %           | Undefined Forest                      | Birch              | Fir   |
| Birch                 | + 3.7 %           | Non-Forest                            | Other Wooded Lands | Fir   |
| Fir                   | + 3.2 %           | Sib. Pine                             | Birch              | Aspen |
| Scots Pine            | + 1.2 %           | Non-Forest                            | Other Wooded Lands | ----  |
| Aspen                 | + 0.7 %           | Non-forest                            | Other Wooded Lands | Fir   |
|                       |                   |                                       |                    |       |
| 1973 Cover Type       |                   | 1990 Result (in order of importance)  |                    |       |
| Sparse Arctic Birch   | - 0.5 %           | Non-Forest                            | Birch              | Fir   |
| Outcrops & Stones     | - 1.5 %           | Sib. Pine                             | Non-forest         | --    |
| Cut or Cleared Forest | - 1.5 %           | Fir                                   | Scots Pine         | Larch |
| Burned Forest         | - 2.6 %           | Non-Forest                            | Birch              | Larch |
| Undefined Forest      | - 10.2 %          | Non-Forest                            | Birch              | Fir   |

Another way of addressing changes between the two maps is to examine which of the major forest types occupy the same sites and have changed the least over time (see Table 1 above). In order of decreasing stability, the forest types are Siberian Pine, Fir, Larch, Scots Pine, Birch and Aspen. Siberian Pine forests are protected (as a food source) and the most stable. Not surprisingly, the least stable forests are composed of the early successional species of Birch and Aspen.

#### **D. Carbon Mapping**

In an effort to learn more about the geographic distribution of carbon across the landscape of the FSU, we have constructed an area-weighted map of carbon using data from Dr. Vladislav Alexeyev and a forest map of the Soviet Union digitized from the 1973 Forest Atlas. The 1973 map (1:15,000,000 scale) is comprised of 22 different cover types: Pine, Spruce, Fir, Spruce/Fir, Larch, Siberian Pine, Juniper, Creeping Cedar, Oak, Beech/Hornbeam, Stone Birch, Sand/Haloxylon, Birch, Aspen, Nonforest, Water, Tilia, other woody and sparse categories. It was digitized here using Roots<sup>™</sup> software and imported into our GIS.

The carbon values for forests (in million of tons, MT, of C), taken with the assistance of Vladislav Alexeyev from Table C-1 of Alexeyev and Birdsey (eds.), Carbon in Ecosystems of Forests and Peatlands of Russia, are the sums of total growing stock of various forest age classes (young, middle-aged, maturing, mature and over-mature). These values were listed by administrative or political district and by forest type.

Forested polygons from the digitized 1973 forest map were assigned carbon values according to the percentage of their area in different tree species. Carbon was assigned to each of the 71 administrative districts of Russia:

$$(Area\ of\ forest\ polygon / Area\ of\ forest\ species) \times Tot.\ MT\ C\ per\ species = Area-weighted\ Carbon$$

Estimating carbon in this manner has certain weaknesses. For instance, we found some disagreement in 68 of 71 administrative districts between the forest tree species described in the 1973 map and those listed by Alexeyev. These disagreements accounted for 4.18% of a published total of  $26.1 \times 10^9$  T C of carbon in tree stands and shrubs. Likely causes for the disagreement are the different scales between the forest map we digitized (1:15M) and administrative district boundary file data (1:8M), the (unknown) scale of the original data used to create the published values of carbon, and the differences between the map classifications that were used. (These differences accounted for less than 1 % of the total carbon mapped).

The newly calculated map is the only map of forest carbon for the Russian territory. We hope to compare it with the "carbon quantifiable region" map from Gaston et al.(1993). To improve this map, we require a reliable administrative boundary layer map.

#### **E. New Maps of the FSU**

In collaboration with NASA Graduate Fellow Dimitry Valyguin we have acquired a 1:4,000,000 scale map of the agricultural regions of the FSU (Rakitnikov and Yanvariova, 1989) and a 1:4,000,000 scale map of the Land Cover and Land Use of the FSU (Yanvariova, Martynuk, and Kiseleva, 1991). With our support, Valyguin has translated the legends into English.

#### **Meetings attended or anticipated during the current Year**

NASA STAC review, Moscow, September 1995  
NASA-Russia Environ. Working Group, Alexandria, June 1996  
Ecological Soc. of America Annual meeting, August 1996  
NASA-Russia Environ. Working Group, Washington, December 1996

#### **Visits by Russians to WHRC (see Appendix B)**

Vladislav Alexeyev, Sukachev Inst., Krasnoyarsk, February, 1996  
Alexander Bondarev, Sukachev Inst., Dec. to March 1996,  
Alexander Lioubimov, St. Petersburg Forest Tech. Acad., March to June 1996  
Igor Danilan, Sukachev Inst., Dec. 1996  
Andrei Laletin, Sukachev Inst., Nov. 1996  
Boris Romanyuk, Research Inst. for For. Mgmt., St. Petersburg, Jan. 1997  
Kira Kobuk of the State Hydrological Inst., St. Petersburg, May 1996  
Marina Botch of the Komarov Botanical Inst., St. Petersburg, May 1996  
Dmitry Varlyguin, NASA Graduate Fellow, Clark Univ., several visits.

Although support for these most of visitors came from private foundations, they bring, nonetheless, great strength to the effort for NASA by the WHRC

#### **Papers submitted, published, or in preparation**

Stone, T.A., and P. Schlesinger, 1994. Building a Spatially Referenced Database of Landcover for the Region of the Former Soviet Union. Pecora 12 Symposium Proceedings, Land Information from Space-Based Systems. Sioux Falls, August 1993. pp. 555-558.

Stone, T. A. and P. Schlesinger, 1994 [abs.]. A Comparison of Satellite-Based and Russian Map-Based Estimates of the Forest Cover of Krasnoyarsk Territory, Siberia. Boreal Forest and Global Change Conference Papers Advance Abstracts, International Boreal Forest Research Assoc., Saskatoon. Sept. 25-28, 1994. p. 83.

Stone T. A. and V. A. Alexeyev. 1995. Joint US Russian Environmental / Ecological Seminar, Washington, DC, May 15-19, 1995. Invited Poster Presentation "Collaborative Mapping Of The Forest Cover of Russia Using Satellite Data".

Bondarev, A. in press. Age Distribution Patterns in Open Boreal Dahurican Larch Forests of Central Siberia, Forest Ecology and Management.

Lioubimov, A., R. Paivinen and T. Stone, in prep. Forest resources and forest inventory of the St. Petersburg (Leningrad) region of Russia.

Stone, T. A., R. A. Houghton and P. Schlesinger, in prep. A Land Cover Map of the Former Soviet Union Based Upon a Time Series of 15 km Resolution NOAA AVHRR Data

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#### **WHRC Staff**

In June 1996, as a follow-up to the May 1995 Chantilly meeting described earlier, T.A. Stone attended a NASA/NOAA/DOD Russian American Environmental Working Group, Forestry Subgroup meeting in Washington, DC. Mr. Stone has been asked to consult with this group and to provide data from our joint research with our Russian colleagues. Several forest test sites have been chosen by this group in the US (Alaska) and Russia. Data on all sites will be shared and reports on the results on the collaboration will be reported at the end of the year to V. P. Gore and at a planned meeting in Washington on December 1996.

In August 1996, T.A. Stone attended the Ecological Society of America Annual Meeting, Providence, where he presented a paper that is based, in part, on the work with Russian colleagues who have come to the Woods Hole Research Center.

## **Appendix A.**

### **Maps digitized**

The 1990 Soviet Potential Vegetation Map at 1:4,000,000 scale. The original version of this map (Inst. of Geography, 1990) had 374 classes of vegetation.

A 1:15,000,000 scale forest cover map of FSU from 1973 Russian Forest Atlas (Soviet Min. of Geodesy and Cartography, 1973).

A 1:2,000,000 scale forest cover map of Krasnoyarsk Kray from the 1973 Russian Forest Atlas (in progress)

A 1:2,500,000 scale forest cover map of Russia. (GUGK, 1990) Sections covering central Siberia and the Russian Far East have been digitized including the territories of Krasnoyarsk, Chita, Amur, Khabarovsk, Primorski, Sakhalin Island, Irkutsk, Buryat and portions of Yakutia.

The S. F. Kurnayev Vegetation Zones Map. This map is provided as a subset to the 1990 Forest cover map. It is a reprint of the 1973 effort by S. F. Kurnayev which attempted a comprehensive forest vegetation classification based on floristics. Scale: 1:10,000,000.

A Geobotanical Map of the Komarov Botanical Institute, 1954. Scale: 1:4,000,000. 252 classes in total. Krasnoyarsk portion digitized. Originally in Conic Projection, but re-projected to a Latitude / Longitude projection.

### **Other Maps generated with satellite imagery**

Krasnoyarsk Territory

Primorski Kray and Southern Khabarovsk Kray (with WWF support)

### **Other data**

System of Landscapes for the USSR: Zones, Sectors and Altitude Divisions, 1:4,000,000. 1988. Chief Admin. of Surveying and Cartography for the Soviet Ministries, USSR, 1988. Origin: Digitized by A. L. Halpin, Univ. of Virginia.

Matthews Vegetation Map (32 classes), Origin: NOAA/EPA Global Ecosystems Database CDROM. Projection: Geographic Latitude/Longitude. Resolution: 1 degree

Olson World Ecosystems (30 classes), Origin: NOAA/EPA Global Ecosystems Database CDROM. Projection: Geographic Latitude/Longitude. Resolution: 1 degree

Henderson-Sellers Vegetation (81 classes), Origin: NOAA/EPA Global Ecosystems Database CDROM. Projection: Geographic Latitude/Longitude. Resolution: 1 degree

Holdridge Standard (40 classes), Origin: NOAA/EPA Global Ecosystems Database CDROM. Projection: Geographic Latitude/Longitude. Resolution: 1/2 degree

Holdridge Combined (15 classes), Origin: NOAA/EPA Global Ecosystems Database CDROM. Projection: Geographic Latitude/Longitude. Resolution: 1/2 degree

## **Appendix B. Visiting MacArthur Russian Forest Scholars**

### **Dr. Vladislav Alexeyev**

Dr. Alexeyev also worked in our Remote Sensing and Geographic Information Systems (RS/GIS) lab extensively while here to help convert his data on Russian forest area, forest stature, and forest growth rates into a spatially explicit form suitable for use in a GIS. In September 1995, Dr. Alexeyev returned here to continue his research with us.

After returning here in February 1996, Dr. Alexeyev traveled with T.A. Stone to the University of New Hampshire to write a joint proposal with a UNH forest ecologist and colleagues at the U.S. Forest Service office in Durham that was submitted to NSF. The proposal was to examine with satellite data and field work an extensive area of forest decline that is likely due to air pollution in the Kemerovo region of central Siberia.. During June and July 1996 Dr. Alexeyev did preliminary field work in the Kemerovo region to evaluate the causes and extent of the decline in the Siberian Fir forests.

### **Dr. Alexander Bondarev**

At the end of November 1995, Dr. Alexander Bondarev arrived in Woods Hole. Dr. Bondarev is an expert on the northern-most forests in the world in the Taimyr peninsula. These forests, at 72° N latitude, may be unusually susceptible to the earliest effects of climate change. The majority of his efforts while here from November to February 1996 was to write up his research results and to plan more field work to the Taimyr and to write proposals for continued support. His efforts resulted in a paper "Age Distribution Patterns In Open Boreal Dahurican Larch Forests Of Central Siberia" now in press in the journal Forest Ecology and Management. To assist Dr. Bondarev with his ongoing research, we purchased GIS software and several dates of Landsat MSS satellite data of his research region. Dr. Bondarev returned from his last field work in the Taimyr at the end of August. Also while here, Dr. Bondarev traveled to University of Toronto to discuss future collaboration with the forestry faculty.

### **Dr. Alexander Lioubimov**

In April 1996, Dr. Alexander Lioubimov of St. Petersburg Forest Technical Academy arrived in Woods Hole. Most of his work was to evaluate the forest inventory system of the Russian Federation as the basis for spatial accuracy assessment of forest resources. Dr. Lioubimov arrived with an extensive collection of forest resource maps, many of which he digitized in our RS/GIS laboratory. To assist him, we purchased, with private foundation support, two LANDSAT TM images of his St. Petersburg field region in addition to GIS software. Dr. Lioubimov has now returned to Russia and is using the satellite data as a tool to update forest resource maps as well as teaching graduate students in St. Petersburg about GIS and map digitization. Much of this work is part of an on-going collaboration with the internationally recognized European Forestry Institute (EFI) in Joensuu, Finland.

Also during his time here, Dr. Lioubimov traveled to Ft. Collins, Colorado where he presented a paper jointly authored with T.A. Stone entitled "A Forest Inventory System of the Russian Federation as the Basis for Spatial Accuracy Assessments of Forest Resources" at the Second International Symposium on Spatial Accuracy in Natural Resources and Environmental Sciences. Later, as an outgrowth of his travel to Ft. Collins, he was invited to visit forest researchers at Michigan Technical University in Houghton, Michigan to discuss joint programs of research which will likely involve graduate students from Russia traveling to Michigan and graduate students from Michigan going to Russia for research and studies.

### **Dr. Boris Romanyuk**

We have invited Dr. Boris Romanyuk, a Sr. Researcher at the Research Institute for Forestry Management in St. Petersburg, for an extended stay here during early 1997. It is expected that Dr. Romanyuk will continue his research here on landscape approaches to forest management, planning, and protection

We are now looking forward to upcoming visits by additional Russians this fall including Andrei Laletin, a forest ecologist from Krasnoyarsk and the Sukachev Institute, now visiting the US. and Igor Danilan, Forest Ecologist from Krasnoyarsk and the Sukachev Institute who is now doing research at Dartmouth College's Department of Environmental Studies.

